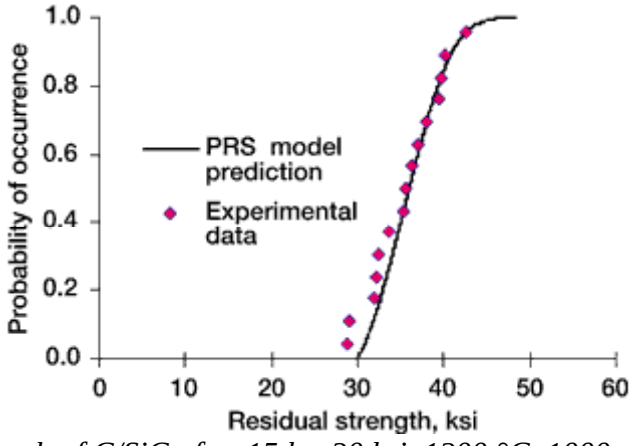
Probabilistic Residual Strength Model Developed for Life Prediction of Ceramic Matrix Composites

For the next generation of reusable launch vehicles, NASA is investigating introducing ceramic matrix composites (CMCs) in place of current superalloys for structural propulsion applications (e.g., nozzles, vanes, combustors, and heat exchangers). The higher use temperatures of CMCs will reduce vehicle weight by eliminating and/or reducing cooling system requirements. The increased strength-to-weight ratio of CMCs relative to superalloys further enhances their weight savings potential. However, in order to provide safe designs for components made of these new materials, a comprehensive life-prediction methodology for CMC structures needs to be developed.

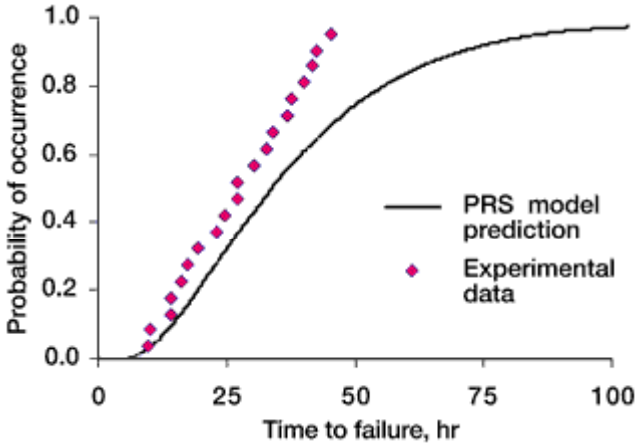
A robust methodology for lifing composite structures has yet to be adopted by the engineering community. Current industry design practice continues to utilize deterministic empirically based models borrowed from metals design for predicting material life capabilities. The deterministic nature of these models inadequately addresses the stochastic character of brittle composites, and their empirical reliance makes predictions beyond the experimental test conditions a risky extrapolation.

A team of engineers at the NASA Glenn Research Center has been developing a new life-prediction engineering model. The Probabilistic Residual Strength (PRS) model uses the residual strength of the composite as its damage metric. Expected life and material strength are both considered probabilistically to account for the observed stochastic material response. Extensive experimental testing has been carried out on C/SiC (a candidate aerospace CMC material system) in a controlled 1000 ppm O_2/argon environment at elevated temperatures of 800 and 1200 °C. The test matrix was established to allow observation of the material behavior, characterization of the model, and validation of the model's predictive capabilities. Sample results of the validation study are illustrated in the graphs.



Residual strength of C/SiC after 15 hr, 30 ksi, 1200 °C, 1000-ppm O_2 exposure.

Long description. Graph of probability of occurrence versus residual strength in kips per square inch for PRS model prediction and experimental data.



Time to failure of C/SiC under 30 ksi, 1200 °C, 1000-ppm O_2 exposure.

Long description. Graph of probability of occurrence versus time to failure in hours for PRS model prediction and experimental data.

Research in this area is ongoing with current efforts focusing on improving the representation of environmental effects within the PRS model. A testing program with SiC/SiC (a material proposed for aerocombustor and aerovane applications) in high-temperature air is also underway.

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